Sedentary Behavior and Physical Activity: Independent, Co-dependent or Irrelevant?

Harold W. (Bill) Kohl, III, Ph.D., MSPH

University of Texas Health Science Center – Houston
School of Public Health
Michael and Susan Dell Center for Healthy Living

The University of Texas at Austin
Department of Kinesiology and Health Education
USA

@billkohl #physicalactivity
Acknowledgments

• Capt. Richard Troiano
• Ms. Heather Steele
• ILSI Energy Balance Committee
Overview

• Definition and framework
• Existing research
• Recommendations
Children’s Games, Pieter Bruegel the Elder, 1560
Current situation
Children’s Games, Pieter Bruegel the Elder, 1560
Current situation
Growth in Sedentary Science Publications

Scopus.com - Articles or reviews: sedentary AND time OR behavior in title
Enter Sedentary Behavior...

- Measurement
- Measurement
- Measurement
Enter Sedentary Behavior...

- Television time
- Sitting time
- Screen time
- Sleep
- Occupational
- Transportation
Definition of Sedentary Behavior

• Activities that do not increase energy expenditure substantially above the resting level.
  • Such as sleeping, sitting, lying down, and watching television, and other forms of screen-based entertainment.
  • Operationally, sedentary behavior includes activities that involve energy expenditure at the level of 1.0-1.5 metabolic equivalent units (METs).

• Light physical activity, is often grouped with sedentary behavior but is in fact a distinct activity construct
  • Such as slow walking, sitting and writing, cooking food, and washing dishes.
  • Involves energy expenditure at the level of 1.6-2.9 METs.

Pate et al 2009
Physical Activity

Recall Cue

Specific Activity Type
  e.g., soccer, lifting heavy boxes or children, walking

Intensity Category
  e.g., light, moderate, vigorous

Characteristic
  Frequency
  Intensity
  Duration
  Pattern

Gabriel et al 2011
Leisure
Occupation
Sleep
Transport

Physical Inactivity

Specific Behavior Type
Sitting, laying, sleeping

Context
Recall Cue

Characteristic
Frequency
Volume
Type
Duration
Pattern

Kohl and Troiano unpublished
Assessing Sitting Across Contexts: Development of the Multicontext Sitting Time Questionnaire

Geoffrey P. Whitfield and Kelley K. Pettee Gabriel
The University of Texas School of Public Health

Harold W. Kohl III
The University of Texas School of Public Health
The University of Texas at Austin

**Purpose:** To describe the development and preliminary evaluation of the Multicontext Sitting Time Questionnaire (MSTQ). **Method:** During development of the MSTQ, contexts and domains of sitting behavior were utilized as recall cues to improve the accuracy of sitting assessment. The terms “workday” and “nonworkday” were used to disambiguate occupational and discretionary sitting. An expert panel evaluated content validity. Among 25 participants, test–retest reliability of the MSTQ items was assessed with intraclass correlation coefficients (ICCs). Convergent validity was assessed versus relative and absolute accelerometer-estimated sedentary time and activity log using Pearson (r) or Spearman (ρ) correlation coefficients where appropriate. **Results:** Pilot testing revealed Web-based MSTQ administration was rapid, scalable, and inexpensive. Most items in the MSTQ demonstrated acceptable reliability (ICCs > .70). Compared with accelerometer-estimated sedentary time relative to total wear time, the MSTQ exhibited a low correlation on workdays (r = .34) and a moderately high correlation on nonworkdays (r = .61). **Conclusions:** The systematic development of the MSTQ resulted in several improvements over previous tools and may serve as a model for purpose-driven questionnaire design. Additional validation is needed to conclusively determine the utility of the MSTQ.
MULTICONTEXT SITTING TIME QUESTIONNAIRE (MSTQ)

What is your current employment status? Please select the answer that requires the most time. For example, if you work full-time and attend school part-time, select “employed for wages.”

1. Employed for wages
2. Self-employed
3. Out of work for more than 1 year
4. Out of work for less than 1 year
5. A homemaker
6. A student
7. Retired
8. Unable to work

How many hours per week do you typically work? ________
In a typical week, what are your primary workdays? (select all that apply)
1. Monday
2. Tuesday
3. Wednesday
4. Thursday
5. Friday
6. Saturday
7. Sunday

The next two questions will ask about the time you spend sleeping and sitting. First, we will ask about a WORKDAY, then a NONWORKDAY.

Think about a usual week. In the lines below, please indicate the number of hours and minutes per WORKDAY you spend doing each of the activities listed. Please do not record time twice in different categories: For example, if you were reading while watching TV, only report that time under one category.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Hours</th>
<th>Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleeping (per night)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting while working, reading, or studying</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting while watching TV or movies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting while using a computer or videogame (nonwork)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting during transportation (not including bicycles)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting while talking, texting, or other socializing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The next question asks about the time you spend sleeping and sitting on a NONWORKDAY.

Think about a usual week. In the lines below, please indicate the number of hours and minutes per NONWORKDAY you spend doing each of the activities listed. Please do not record time twice in different categories: For example, if you were reading while watching TV, only report that time under one category.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Hours</th>
<th>Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleeping (per night)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting while working, reading, or studying</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting while watching TV or movies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting while using a computer or videogame (nonwork)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting during transportation (not including bicycles)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting while talking, texting, or other socializing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Do your answers in the sleeping/sitting-time questions reflect your normal activity levels?
(Yes/No)

At any time during the past 2 weeks, was your ability to move reduced due to injury or illness?
(Yes/No)
Sedentary and Active: Self-Reported Sitting Time Among Marathon and Half-Marathon Participants

Geoffrey Whitfield, Kelley K. Pettee Gabriel, and Harold W. Kohl III

Background: Emerging evidence suggests that combined physical activity (PA) and inactivity may be more important for chronic disease risk than PA alone. A highly active yet highly sedentary population is needed to study this interaction. The present purpose is to describe the sitting habits of a group of recreational runners and determine if sitting varies with reported training duration or anticipated running velocity. Methods: Marathon and half-marathon participants completed the Multicontext Sitting Time Questionnaire and reported peak training duration, anticipated finishing time, and demographic information. Sitting time was described across 5 contexts for workdays and nonworkdays. Total sitting time was analyzed by tertiles of training duration and anticipated event running velocity. Results: 218 participants took part in this study. Median reported training time was 6.5 hours per week. Median total sitting time was higher on workdays than nonworkdays (645 and 480 minutes, respectively, P < .0001). Total sitting time was not associated with training duration or anticipated event running velocity. Conclusions: These results suggest that recreational distance runners are simultaneously highly sedentary and highly active, supporting independence of sedentary behaviors and moderate- to vigorous-intensity PA. This population may provide the characteristics needed to study the joint effects of active and sedentary behaviors on health outcomes.

Keywords: physical activity, epidemiology, endurance athletes, internet survey
Figure 1 — Contribution of each context to the total minutes of reported sitting for workdays and non-workdays.
Competitive runners sit more than 10 hours/day!

Figure 1: Median reported sitting, context-specific and total

Whitfield et al 2014
Duration and breaks in sedentary behaviour: accelerometer data from 1566 community-dwelling older men (British Regional Heart Study)

Barbara J Jefferis, Claudio Sartini, Eric Shiroma, Peter H Whincup, S Goya Wannamethee, I-Min Lee

ABSTRACT

Background Sedentary behaviours are increasingly recognised as raising the risk of cardiovascular disease events, diabetes and mortality, independently of physical activity levels. However, little is known about patterns of sedentary behaviour in older adults.

Methods Cross-sectional study of 1566/3137 (50% response) men aged 71–91 years from a UK population-based cohort study. Men wore a GT3x accelerometer over the hip for 1 week in 2010–2011. Mean daily minutes of sedentary behaviours, percentage of day in sedentary behaviours, sedentary bouts and breaks were calculated and summarised by health and demographic characteristics.

Results 1403 ambulatory men aged 78.4 years (SD=4.6 years) with ≥600 min of accelerometer wear on ≥3 days had complete data on covariables. Men spent on average 618 min (SD=83), or 72% of their day in sedentary behaviours (<100 counts/min). On average, men accumulated 72 spells of sedentary behaviours per day, with 7 breaks in each sedentary hour. Men had on average 5.1 sedentary bouts of ≥30 min, which time captures only a fraction of the daily sedentary behaviours.

The recent availability of instruments to measure PA and sedentary behaviours objectively permits a more detailed investigation of patterns of sedentary behaviours, including the duration of spells and frequency of breaks in sedentary time. Older adults (over 65 years) are the most sedentary age group and also the most rapidly growing age group in the UK and other developed countries. However, little is known about the actual patterns of sedentary behaviour in older adults; such data could be important for targeting interventions if breaking up sedentary behaviour is demonstrated to reduce clinical disease and mortality, and bouts of a particular duration are associated with negative outcomes. A recent study reported on accelerometer measured sedentary behaviour patterns and associations with key lifestyle factors in older women. There are few comparable data available in older men. We therefore investigated patterns of sedentary behaviour in relation to these variables, as well as physical and
<table>
<thead>
<tr>
<th>Age group</th>
<th>Number of men (%)</th>
<th>Sedentary behaviour (min/day) Mean (95% CI)</th>
<th>p Value</th>
<th>Wear time in sedentary behaviour* (%) Mean (95% CI)</th>
<th>p Value</th>
<th>Number of bouts sedentary behaviour/day† Mean (95% CI)</th>
<th>p Value</th>
<th>Number of breaks per sedentary hour‡ Mean (95% CI)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All men§**</td>
<td>1403</td>
<td>618 (614 to 621)</td>
<td>&lt;0.001</td>
<td>72.4 (72.0 to 72.8)</td>
<td></td>
<td>71.9 (71.2 to 72.6)</td>
<td></td>
<td>7.2 (7.1 to 7.3)</td>
<td></td>
</tr>
<tr>
<td>70 to &lt;75 years</td>
<td>389 (27.7)</td>
<td>602 (595 to 609)</td>
<td>&lt;0.001</td>
<td>69.7 (68.9 to 70.5)</td>
<td>&lt;0.001</td>
<td>73.4 (72.2 to 74.6)</td>
<td>&lt;0.001</td>
<td>7.6 (7.4 to 7.8)</td>
<td></td>
</tr>
<tr>
<td>75 to &lt;80 years</td>
<td>544 (38.8)</td>
<td>610 (603 to 616)</td>
<td></td>
<td>71.2 (70.5 to 72.0)</td>
<td></td>
<td>72.7 (71.6 to 73.8)</td>
<td></td>
<td>7.4 (7.2 to 7.6)</td>
<td></td>
</tr>
<tr>
<td>≥80 years</td>
<td>470 (33.5)</td>
<td>641 (635 to 647)</td>
<td></td>
<td>76.0 (75.3 to 76.7)</td>
<td></td>
<td>69.6 (68.3 to 70.9)</td>
<td></td>
<td>6.7 (6.5 to 6.9)</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td></td>
<td></td>
<td>0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;25</td>
<td>406 (28.9)</td>
<td>614 (606 to 621)</td>
<td>&lt;0.001</td>
<td>71.5 (70.6 to 72.3)</td>
<td>&lt;0.001</td>
<td>74.5 (73.2 to 75.8)</td>
<td>&lt;0.001</td>
<td>7.5 (7.3 to 7.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>25 to &lt;30</td>
<td>722 (51.5)</td>
<td>613 (608 to 618)</td>
<td></td>
<td>71.7 (71.1 to 72.3)</td>
<td></td>
<td>72.7 (71.7 to 73.7)</td>
<td></td>
<td>7.4 (7.2 to 7.5)</td>
<td></td>
</tr>
<tr>
<td>≥30</td>
<td>275 (19.6)</td>
<td>637 (629 to 644)</td>
<td></td>
<td>75.7 (74.8 to 76.5)</td>
<td></td>
<td>65.7 (64.1 to 67.3)</td>
<td></td>
<td>6.4 (6.2 to 6.6)</td>
<td></td>
</tr>
<tr>
<td>Smoking status</td>
<td></td>
<td></td>
<td>0.012</td>
<td></td>
<td>0.073</td>
<td></td>
<td>0.008</td>
<td></td>
<td>0.297</td>
</tr>
<tr>
<td>Non-smoker</td>
<td>1356 (96.7)</td>
<td>617 (613 to 620)</td>
<td></td>
<td>72.3 (71.9 to 72.7)</td>
<td></td>
<td>71.7 (71.0 to 72.4)</td>
<td></td>
<td>7.2 (7.1 to 7.3)</td>
<td></td>
</tr>
<tr>
<td>Smoker</td>
<td>47 (3.3)</td>
<td>649 (627 to 671)</td>
<td>&lt;0.001</td>
<td>74.9 (72.4 to 77.4)</td>
<td>&lt;0.001</td>
<td>77.6 (73.3 to 82.0)</td>
<td>&lt;0.001</td>
<td>7.5 (6.9 to 8.2)</td>
<td></td>
</tr>
<tr>
<td>Depression</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not depressed</td>
<td>1094 (78.0)</td>
<td>613 (609 to 617)</td>
<td>&lt;0.001</td>
<td>71.3 (70.8 to 71.8)</td>
<td>&lt;0.01</td>
<td>73.1 (72.3 to 73.9)</td>
<td>&lt;0.001</td>
<td>7.4 (7.3 to 7.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Depressed</td>
<td>309 (22.0)</td>
<td>634 (626 to 642)</td>
<td>&lt;0.001</td>
<td>76.4 (75.4 to 77.3)</td>
<td>&lt;0.001</td>
<td>67.4 (65.8 to 68.9)</td>
<td>&lt;0.001</td>
<td>6.6 (6.4 to 6.8)</td>
<td></td>
</tr>
<tr>
<td>Chronic conditions</td>
<td></td>
<td></td>
<td>&lt;0.001</td>
<td></td>
<td>&lt;0.001</td>
<td></td>
<td>&lt;0.001</td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>None</td>
<td>657 (46.8)</td>
<td>621 (615 to 627)</td>
<td>&lt;0.001</td>
<td>73.0 (72.3 to 73.7)</td>
<td>&lt;0.001</td>
<td>71.3 (70.1 to 72.5)</td>
<td>&lt;0.001</td>
<td>7.1 (6.9 to 7.3)</td>
<td></td>
</tr>
<tr>
<td>1–2</td>
<td>644 (45.9)</td>
<td>630 (619 to 640)</td>
<td></td>
<td>74.4 (73.1 to 75.6)</td>
<td></td>
<td>69.4 (67.4 to 71.4)</td>
<td></td>
<td>6.9 (6.6 to 7.2)</td>
<td></td>
</tr>
<tr>
<td>≥3</td>
<td>102 (7.3)</td>
<td>652 (637 to 667)</td>
<td></td>
<td>78.3 (76.5 to 80.1)</td>
<td></td>
<td>66.6 (63.3 to 70.0)</td>
<td></td>
<td>6.3 (5.9 to 6.8)</td>
<td></td>
</tr>
</tbody>
</table>

*Percentage sedentary=100×sedentary (<100 cpm) minutes/total wear time (min).
†A bout of sedentary behaviour is a period of consecutive minutes where the accelerometer registers <100 cpm.
‡A break in sedentary behaviour is at least one minute where the accelerometer registers >100 cpm following a sedentary bout.
§Marginal means are adjusted for age, BMI, smoking status, wear time, day order of week, number of chronic diseases and depression.
‖p Value tests for equal means across all levels of the subgroup.
**Ambulatory men, not in a care home, no missing covariate data.
††Pairwise mean difference p<0.05 when compared to age <75, BMI <25, non-smoker, not depressed, or 0 chronic conditions.
BMI, body mass index.

Jefferis et al 2014
2008 Physical Activity Guidelines for Americans

Be Active, Healthy, and Happy!

www.health.gov/paguidelines
Inactivity

• “All adults should avoid inactivity. Some physical activity is better than none, and adults who participate in any amount of physical activity gain some health benefits.”
Sitting Time and Mortality from All Causes, Cardiovascular Disease, and Cancer

PETER T. KATZMARZYK¹, TIMOTHY S. CHURCH¹, CORA L. CRAIG², and CLAUDE BOUCHARD¹

¹Pennington Biomedical Research Center, Baton Rouge, LA; and ²Canadian Fitness and Lifestyle Research Institute, Ottawa, Ontario, CANADA

ABSTRACT

KATZMARZYK, P. T., T. S. CHURCH, C. L. CRAIG, and C. BOUCHARD. Sitting Time and Mortality from All Causes, Cardiovascular Disease, and Cancer. Med. Sci. Sports Exerc., Vol. 41, No. 5, pp. 998–1005, 2009. Purpose: Although moderate-to-vigorous physical activity is related to premature mortality, the relationship between sedentary behaviors and mortality has not been fully explored and may represent a different paradigm than that associated with lack of exercise. We prospectively examined sitting time and mortality in a representative sample of 17,013 Canadians 18–90 yr of age. Methods: Evaluation of daily sitting time (almost none of the time, one fourth of the time, half of the time, three fourths of the time, almost all of the time), leisure time physical activity, smoking status, and alcohol consumption was conducted at baseline. Participants were followed prospectively for an average of 12.0 yr for the ascertainment of mortality status. Results: There were 1832 deaths (759 of cardiovascular disease (CVD) and 547 of cancer) during 204,732 person-yr of follow-up. After adjustment for potential confounders, there was a progressively higher risk of mortality across higher levels of sitting time from all causes (hazard ratios (HR): 1.00, 1.00, 1.11, 1.36, 1.54; P for trend < 0.0001) and CVD (HR: 1.00, 1.01, 1.22, 1.47, 1.54; P for trend < 0.0001) but not cancer. Similar results were obtained when stratified by sex, age, smoking status, and body mass index. Age-adjusted all-cause mortality rates per 10,000 person-yr of follow-up were 87, 86, 105, 130, and 161 (P for trend < 0.0001) in physically inactive participants and 75, 69, 76, 98, 105 (P for trend = 0.008) in active participants across sitting time categories. Conclusions: These data demonstrate a dose–response association between sitting time and mortality from all causes and CVD, independent of leisure time physical activity. In addition to the promotion of moderate-to-vigorous physical activity and a healthy weight, physicians should discourage sitting for extended periods. Key Words: PHYSICAL ACTIVITY, SEDENTARY BEHAVIOR, COHORT, DEATH, SURVIVAL
Sitting Time Prospectively Associated with Early Mortality

Katzmarzyk et al 2009
...independent of physical activity

Katzmarzyk et al 2009
Standing and Mortality in a Prospective Cohort of Canadian Adults

PETER T. KATZMARZYK

Pennington Biomedical Research Center, Baton Rouge, LA

ABSTRACT

KATZMARZYK, P. T. Standing and Mortality in a Prospective Cohort of Canadian Adults. Med. Sci. Sports Exerc., Vol. 46, No. 5, pp. 940–946, 2014. Purpose: Several studies have documented significant associations between sedentary behaviors such as sitting or television viewing and premature mortality. However, the associations between mortality and other low-energy-expenditure activities such as standing have not been explored. The purpose of this study was to examine the association between daily standing time and mortality among 16,586 Canadian adults 18–90 yr of age. Methods: Information on self-reported time spent standing as well as several covariates including smoking, alcohol consumption, physical activity readiness, and moderate-to-vigorous physical activity was collected at baseline in the 1981 Canada Fitness Survey. Participants were followed for an average of 12.0 yr for the ascertainment of mortality status. Results: There were 1785 deaths (743 from cardiovascular disease [CVD], 530 from cancer, and 512 from other causes) in the cohort. After adjusting for age, sex, and additional covariates, time spent standing was negatively related to mortality rates from all causes, CVD, and other causes. Across successively higher categories of daily standing, the multivariable-adjusted hazard ratios were 1.00, 0.79, 0.79, 0.73, and 0.67 for all-cause mortality (P for trend <0.0001); 1.00, 0.82, 0.84, 0.68, and 0.75 for CVD mortality (P for trend 0.02); and 1.00, 0.76, 0.63, 0.67, and 0.65 for other mortality (P for trend <0.001). There was no association between standing and cancer mortality. There was a significant interaction between physical activity and standing (P < 0.05), and the association between standing and mortality was significant only among the physically inactive (<7.5 MET-h wk⁻¹). Conclusions: The results suggest that standing may not be a hazardous form of behavior. Given that mortality rates declined at higher levels of standing, standing may be a healthier alternative to excessive periods of sitting. Key Words: POSTURE, STANDING, PHYSICAL ACTIVITY, CANADA FITNESS SURVEY, DEATH, COHORT
Standing Time Prospectively Associated with Early Mortality
...but not independent of physical activity
Sedentary Time and Its Association With Risk for Disease Incidence, Mortality, and Hospitalization in Adults
A Systematic Review and Meta-analysis
Aviroop Biswas, BSc; Paul I. Oh, MD, MSc; Guy E. Faulkner, PhD; Ravi R. Bajaj, MD; Michael A. Silver, BSc; Marc S. Mitchell, MSc; and David A. Alter, MD, PhD

**Background:** The magnitude, consistency, and manner of association between sedentary time and outcomes independent of physical activity remain unclear.

**Purpose:** To quantify the association between sedentary time and hospitalizations, all-cause mortality, cardiovascular disease, diabetes, and cancer in adults independent of physical activity.

**Data Sources:** English-language studies in MEDLINE, PubMed, EMBASE, CINAHL, Cochrane Library, Web of Knowledge, and Google Scholar databases were searched through August 2014 with hand-searching of in-text citations and no publication date limitations.

**Study Selection:** Studies assessing sedentary behavior in adults, adjusted for physical activity and correlated to at least 1 outcome.

**Data Extraction:** Two independent reviewers performed data abstraction and quality assessment, and a third reviewer resolved inconsistencies.

**Data Synthesis:** Forty-seven articles met our eligibility criteria. Meta-analyses were performed on outcomes for cardiovascular disease and diabetes (14 studies), cancer (14 studies), and all-cause mortality (13 studies). Prospective cohort designs were used in all but 3 studies; sedentary times were quantified using self-report in all but 1 study. Significant hazard ratio (HR) associations were found with all-cause mortality (HR, 1.240 [95% CI, 1.090 to 1.410]), cardiovascular disease mortality (HR, 1.179 [CI, 1.106 to 1.257]), cardiovascular disease incidence (HR, 1.143 [CI, 1.002 to 1.729]), cancer mortality (HR, 1.173 [CI, 1.108 to 1.242]), cancer incidence (HR, 1.130 [CI, 1.053 to 1.213]), and type 2 diabetes incidence (HR, 1.910 [CI, 1.642 to 2.222]). Hazard ratios associated with sedentary time and outcomes were generally more pronounced at lower levels of physical activity than at higher levels.

**Limitation:** There was marked heterogeneity in research designs and the assessment of sedentary time and physical activity.

**Conclusion:** Prolonged sedentary time was independently associated with deleterious health outcomes regardless of physical activity.

**Primary Funding Source:** None.

For author affiliations, see end of text.
Biswas et al. 2015

Records identified (n = 21,005)
  Identified through database searching: 20,980
  Identified through other sources: 25

Duplicates removed (n = 5256)

Records after duplicates removed (n = 15,749)

Excluded because they did not satisfy criteria
  (n = 15,641)

Records screened for eligibility (n = 108)

Records excluded due to sampling of nonadults, lack of adjustment for physical activity in regression models, lack of definitive outcomes in prevalence studies, sedentary behavior defined as low physical activity, and lack of statistical reporting in results
  (n = 61)

Full-text articles included in qualitative synthesis (n = 47)

Studies excluded due to unclear presentation of statistical effect sizes (n = 6)

Studies included in quantitative synthesis
  (meta-analysis) (n = 41)
    All-cause mortality: 13
    Cardiovascular disease-related incidence and mortality: 9
    Cancer-related incidence and mortality: 14
    Type 2 diabetes incidence: 5
Sedentary behavior and non-communicable disease outcome

Adapted from Biswas et al 2015
**Sedentary behavior, physical activity and all-cause mortality**

Adapted from Biswas et al 2015
Sitting Time and All-Cause Mortality Risk in 222 497 Australian Adults

Hidde P. van der Ploeg, PhD; Tien Chey, MAppStats; Rosemary J. Korda, PhD; Emily Banks, MBBS, PhD; Adrian Bauman, MBBS, PhD

**Background:** Prolonged sitting is considered detrimental to health, but evidence regarding the independent relationship of total sitting time with all-cause mortality is limited. This study aimed to determine the independent relationship of sitting time with all-cause mortality.

**Methods:** We linked prospective questionnaire data from 222 497 individuals 45 years or older from the 45 and Up Study to mortality data from the New South Wales Registry of Births, Deaths, and Marriages (Australia) from February 1, 2006, through December 31, 2010. Cox proportional hazards models examined all-cause mortality in relation to sitting time, adjusting for potential confounders that included sex, age, education, urban/rural residence, physical activity, body mass index, smoking status, self-rated health, and disability.

**Results:** During 621 695 person-years of follow-up (mean follow-up, 2.8 years), 5405 deaths were registered. All-cause mortality hazard ratios were 1.02 (95% CI, 0.95-1.09), 1.15 (1.06-1.25), and 1.40 (1.27-1.55) for 4 to less than 8, 8 to less than 11, and 11 or more h/d of sitting, respectively, compared with less than 4 h/d, adjusting for physical activity and other confounders. The population-attributable fraction for sitting was 6.9%. The association between sitting and all-cause mortality appeared consistent across the sexes, age groups, body mass index categories, and physical activity levels and across healthy participants compared with participants with preexisting cardiovascular disease or diabetes mellitus.

**Conclusions:** Prolonged sitting is a risk factor for all-cause mortality, independent of physical activity. Public health programs should focus on reducing sitting time in addition to increasing physical activity levels.

*Arch Intern Med. 2012;172(6):494-500*
Association being driven by pre-existing disease? Especially cardiometabolic disease?

Van der Ploeg et al 2013
Physical Activity and Health Conceptual Framework

Physical Activity Exposure

- Intensity
- Frequency
- Duration
- Pattern
- Type
- Caloric Expenditure

Cardio-vascular/Respiratory Health (including CHD, PVD, Stroke)

Metabolic Health (including Diabetes Mellitus and Obesity)

Musculo-skeletal Health (including Osteoporosis)

Cancers

Functional Health

Mental Health

All-Cause Mortality

Health Outcomes

Risk Factors

Adverse events and Risks of Physical Activity

Examples
- Dyslipidemias
- Blood Pressure
- Hemostatic/Coagulation Factors
- Asthma
- Fitness
- Cardiac Function
- Lung Function

Examples
- Insulin Resistance
- Insulin Sensitivity
- Glucose uptake
- Metabolic Syndrome
- Overweight
- Constipation
- Fitness
- Hormonal influences
- Sleep quality

Examples
- Bone mineralization
- Flexibility
- Strength
- Balance
- Maturity/Growth
- Fitness
- Motor skill development
- Muscle fiber

Examples
- Bowel transit time
- Hormonal factors
- Immune Function
- Linkages with other behaviors.

Examples
- Quality of life
- Functional independence
- Balance
- Pain
- Fall prevention
- Cognitive Function

Examples
- Anxiety
- Self-concept
- Sleep quality

Examples
- Strength
- Balance
- Fitness
- Previous Injury
- Family history
Physical Inactivity, Sedentary Behaviors and Health Conceptual Framework

Physical Inactivity
- Volume of inactivity
  - Frequency
  - Duration
  - Volume of physical activity

Sedentary Behavior
- Pattern
- Timing
- Type

Cardiovascular/Respiratory Health (including CHD, PVD, Stroke)
- Examples
  - Dyslipidemias
  - Blood Pressure
  - Hemostatic/Coagulation Factors
  - Asthma
  - Fitness
  - Cardiac Function
  - Lung Function

Metabolic Health (including Diabetes Mellitus and Obesity)
- Examples
  - Insulin Resistance
  - Insulin Sensitivity
  - Glucose uptake
  - Metabolic Syndrome
  - Overweight
  - Constipation
  - Fitness
  - Hormonal Influences
  - Sleep quality

Musculo-skeletal Health (including Osteoporosis)
- Examples
  - Bone mineralization
  - Flexibility
  - Strength
  - Balance
  - Maturation/Growth
  - Motor skill development
  - Muscle fiber

Cancers
- Examples
  - Bowel transit time
  - Hormonal factors
  - Immune Function
  - Linkages with other behaviors.

Mental Health
- Examples
  - Anxiety
  - Self-concept
  - Sleep quality

Function- al Health
- Examples
  - Pain
  - ADL
  - PHQoL

Health Outcomes
- All-Cause Mortality

Mechanisms
- Kohl and Troiano unpublished
Conclusions

- Sedentary behavior has been measured/used in a variety of ways.
- Can make up a large portion of a day, even for very active people.
- A consistent definition and framework for research must be applied.
- Data suggest some kind of independent association (or not) with health outcomes – sitting, not standing.
- Unclear if it is real or an artifact of measurement.
- Early mechanistic studies suggest directions but none support independent associations.
**Recommendations**

- Although the full range of activity intensities (sedentary to vigorous) contribute to total energy expenditure, activity performed within a narrow intensity range (e.g., vigorous) may influence health in ways that are unique from other activity intensities.
- Conclusions of studies should be phrased carefully so as to be consistent with the activity variables that were actually measured in the study.
- Care should be taken to avoid discussing “replacing” reduction in sedentary behavior for meeting physical activity guidelines.
- Mechanistic studies are urgently needed.
- Physiologic principles of overload, specificity and adaptation still apply.
Physical Inactivity, Sedentary Behaviors and Health Conceptual Framework

**Physical Inactivity**
- Volume of inactivity
  - Frequency
  - Duration
  - Volume of physical activity
  - Pattern
  - Timing
  - Type

**Sedentary Behavior**

**Cardiovascular/Respiratory Health (including CHD, PVD, Stroke)**
- Examples
  - Dyslipidemias
  - Blood Pressure
  - Hemostatic/Coagulation Factors
  - Asthma
  - Fitness
  - Cardiac Function
  - Lung Function

**Metabolic Health (including Diabetes Mellitus and Obesity)**
- Examples
  - Insulin Resistance
  - Insulin Sensitivity
  - Glucose uptake
  - Metabolic Syndrome
  - Overweight
  - Constipation
  - Fitness
  - Hormonal influences
  - Sleep quality

**Musculoskeletal Health (including Osteoporosis)**
- Examples
  - Bone mineralization
  - Hormonal factors
  - Strength Balance
  - Maturation/Growth
  - Fitness
  - Motor skill development
  - Muscle fiber

**Cancers**
- Examples
  - Bowel transit time
  - Adiposity
  - Hormonal Function
  - Linkages with other behaviors.

**Functional Health**
- Examples
  - Pain
  - ADL
  - FHQoL

**Mental Health**
- Examples
  - Anxiety
  - Self-concept
  - Sleep quality
  - Mood

**Mechanisms**

**Health Outcomes**

**All-Cause Mortality**

Kohl and Troiano unpublished
Enter Sedentary Behavior...

• Mechanisms
• Mechanisms
• Mechanisms
"I think you should be more explicit here in step two."
Physiology of Sedentary Behavior and Its Relationship to Health Outcomes

John P. Thyfault¹, Mengmeng Du², William E. Kraus³, James A Levine⁴, and Frank W. Booth¹

¹University of Missouri, Columbia, MO; ²Fred Hutchinson Cancer Research Center, Seattle, WA; ³Duke University, Durham, NC; ⁴Mayo Clinic, Minneapolis, MN
Mechanisms?

- Aerobic capacity
- Skeletal muscle metabolism and function
- Telomeres/genetic stability
- Cognitive function

- Overload, Specificity, Adaptation
Objective—Observational studies show breaking up prolonged sitting has beneficial associations with cardiometabolic risk markers, but intervention studies are required to investigate causality. We examined the acute effects on postprandial glucose and insulin levels of uninterrupted sitting compared with sitting interrupted by brief bouts of light- or moderate-intensity walking.

Research Design and Methods—Overweight/obese adults (n = 19), aged 45–65 years, were recruited for a randomized three-period, three-treatment acute crossover trial: 1) uninterrupted sitting; 2) seated with 2-min bouts of light-intensity walking every 20 min; and 3) seated with 2-min bouts of moderate-intensity walking every 20 min. A standardized test drink was provided after an initial 2-h period of uninterrupted sitting. The positive incremental area under curves (iAUC) for glucose and insulin (mean [95% CI]) for the 5 h after the test drink (75 g glucose, 50 g fat) were calculated for the respective treatments.

Results—The glucose iAUC (mmol/L) • h after both activity-break conditions was reduced (light: 5.2 [4.1–6.6]; moderate: 4.9 [3.8–6.1]; both P < 0.01) compared with uninterrupted sitting (6.9 [5.5–8.7]). Insulin iAUC (pmol/L) • h was also reduced with both activity-break conditions (light: 633.6 [552.4–727.1]; moderate: 637.6 [555.5–731.9]; P < 0.0001) compared with uninterrupted sitting (828.6 [722.0–950.9]).

Conclusions—Interrupting sitting time with short bouts of light- or moderate-intensity walking lowers postprandial glucose and insulin levels in overweight/obese adults. This may improve metabolism and potentially be an important public health and clinical intervention strategy for reducing cardiovascular risk.

Diabetes Care 35:976–983, 2012

and was characterized by light-intensity activity (approximately 500 accelerometer counts/min). Furthermore, these relationships persisted after accounting for moderate-to-vigorous activity, suggesting that frequent short breaks in sedentary time may impart unique benefit. A next step for the science of sedentary behavior is to identify the metabolic underpinnings of these deleterious and beneficial relationships.

Regular ingestion of high-calorie meals rich in processed carbohydrates and saturated fat can lead to transient exaggerated postprandial spikes in glucose and lipids, which promote oxidative stress that triggers a biochemical inflammatory cascade, endothelial dysfunction, and sympathetic hyperactivity (5–9). These postprandial excursions, when repeated multiple times each day, can create a milieu conducive for the development of atherosclerosis and cardiovascular disease (9,10). Postprandial hyperglycemia or glucose variability has been associated with indices of atherosclerotic progression, including carotid intima-media thickening (11,12) and coronary artery calcium (13) as well as development or progression of retinopathy (14,15), cardiovascular events (16), and death (17) in
Dunstan et al 2012

- n=19 overweight/obese adults
- Age 45-65 years
- Three treatment crossover trial:
  - Uninterrupted sitting
  - Sitting with 2-min bouts of light-intensity physical activity every 20 mins
  - Sitting with 2-min bouts of moderate-intensity physical activity every 20 mins
- Glucose tolerance test – area under curves for insulin and glucose
24-30% reduction in plasma glucose AUC after activity break conditions – increased insulin sensitivity?

2-h post load glucose highest in Uninterrupted Sitting condition

Dunstan et al 2012
23% reduction in insulin AUC after activity break conditions – reduced insulin secretion?

Dunstan et al 2012
Alternating Bouts of Sitting and Standing Attenuates Postprandial Glucose Responses

Alicia A. Thorp\textsuperscript{1,3}, Bronwyn A. Kingwell\textsuperscript{1,4}, Parneet Sethi\textsuperscript{1}, Louise Hammond\textsuperscript{1}, Neville Owen \textsuperscript{1,2,7}, and David W. Dunstan\textsuperscript{1-6}

\textsuperscript{1}Baker IDI Heart and Diabetes Institute, Melbourne, Victoria, Australia; \textsuperscript{2}School of Population Health, The University of Queensland, Brisbane, Australia; \textsuperscript{3}School of Public Health \& Preventive Medicine, Monash University, Melbourne, Australia; \textsuperscript{4}Department of Physiology, Monash University, Melbourne, Australia; \textsuperscript{5}School of Sport Science, Exercise \& Health, University of Western Australia, Perth, Australia; \textsuperscript{6}School of Exercise \& Sports Science, Deakin University, Melbourne, Australia; \textsuperscript{7}School of Population and Global Health, Melbourne University, Melbourne, Australia
Thorp et al 2014

- n=23 overweight/obese adults
- Age 45-65 years
- Five day simulated office environment crossover:
  - Seated work for 8 hours
  - Interchanging seated and standing every 30 mins
- Glucose tolerance test – area under curves for insulin and glucose; triglyceride response.
Differences in change in glucose AUC but not insulin – increased insulin sensitivity?

Thorp et al 2014
Effect of Prolonged Sitting and Breaks in Sitting Time on Endothelial Function

Saurabh S. Thosar\textsuperscript{1}, Sylvanna L. Bielko\textsuperscript{1}, Kieren J. Mather\textsuperscript{2}, Jeanne D. Johnston\textsuperscript{1}, and Janet P. Wallace\textsuperscript{1}

\textsuperscript{1}Department of Kinesiology, Indiana University School of Public Health, Indiana University Bloomington, IN; \textsuperscript{2}Department of Medicine, Indiana University School of Medicine, Indianapolis, IN
Thosar et al, 2014

• 12 non-obese men
• 24.2 years of age (mean)
• Two randomized 3-hour sitting trials
  – Sitting 3-hours uninterrupted
  – Sitting interrupted by 5-min treadmill breaks at 30 mins and at each hour (2 mph).
• Superficial femoral artery flow-mediated dilation and shear rate
Decline in FMD attenuated with active breaks

Thosar et al 2014
Stand up for health—avoiding sedentary behaviour might lengthen your telomeres: secondary outcomes from a physical activity RCT in older people

Per Sjögren, 1 Rachel Fisher, 2 Lena Kallings, 3 Ulrika Svenson, 4 Göran Roos, 4 Mai-Lis Hellénius 5

ABSTRACT
Background Telomere length has been associated with a healthy lifestyle and longevity. However, the effect of increased physical activity on telomere length is still unknown. Therefore, the aim was to study the relationship between changes in physical activity level and sedentary behaviour and changes in telomere length.

Methods Telomere length was measured in blood cells 6 months apart in 49, 68-year-old, sedentary, overweight individuals taking part in a randomised controlled physical activity intervention trial. The intervention group received individualised physical activity on prescription. Physical activity was measured with a 7-day diary, questionnaires and a pedometer. Sitting time was measured with the short version of The International Physical Activity Questionnaire.

Results Time spent exercising as well as steps per day increased significantly in the intervention group. Reported sitting time decreased in both groups. No significant associations between changes in steps per day and changes in telomere length were noted. In the telomere length in postural muscle was similar in young and old people who were physically active. In a Finnish study, physical activity level in mid-life was associated with telomere length in white blood cells after a 29-year follow-up. Interestingly, those reporting moderate physical activity, in comparison with low-intensity or high-intensity physical activity, had significantly longer telomeres. Smoking, stress and major depression are associated with shorter telomeres. Physical activity seems to counteract the deleterious effects of stress on telomere length. However, due to a lack of intervention studies, it is still largely unknown whether introduced lifestyle changes can affect telomere length.

We previously reported a clinical trial where 101 68-year-old individuals (57% women) with a sedentary lifestyle, overweight and abdominal obesity were randomised to individualised physical activity on prescription (intervention) or usual care with minimal intervention (controls). After 6 months, the intervention group had significantly increased
Sjögren et al, 2014

- n=49 sedentary, overweight men and women
- 68 years of age (mean)
- 6-month clinical trial of individualized physical activity intervention.
  - Treatment – behavioral intervention
  - Control
- Blood cell telomere length analyzed by changes in time spent in physical activity and by changes in time spent sitting.
  - Sitting time measured using short IPAQ.
Figure 1  (A and B) Relationship between changes in telomere length (per month) and changes in exercise time of at least moderate intensity (min/week) over 6 months in individuals receiving minimal intervention (A, control, n=21) or individualised physical activity on prescription (B, intervention, n=21). Rho and p Values derived from Spearman rank correlation.

Figure 2  (A and B) Relationship between changes in telomere length (per month) and changes in sitting time during week days (h/day) over 6 months in individuals receiving minimal intervention (A, control, n=12) or individualised physical activity on prescription (B, intervention, n=12). r and p Values derived from Spearman rank correlation.